NEW EFFICIENCY MONITORING AND CONTROL TECHNOLOGY USING SYNCHROPHASOR

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SUMMARY

The current method of operation of transmission and distribution networks leads to their full use up to overloading. As a result of this congestion, critical conditions appear more frequently at all voltage levels and also outages can appear in worst case.

The causes of this are multiple, from economic reasons (reduction of investment, separation of power generation, transmission and distribution etc.) to technical (extensive transmission system, lower behavior predictability of large numbers of small sources).

Systems based on monitoring of large networks using synchrophasor measurement are known as Wide Area Monitoring Systems (WAMS). WAMS together with other bound systems (Wide Area Control - WAC and Wide Area Protection – WAP) allow monitoring and evaluation of operation of interconnected systems in real time and provide global view of the monitored systems.

In this paper we describe the synchrophasor-based WAM technology particularly with regard to usage in distribution networks. The information contained here comes from experience with deployment and operation of WAM system in distribution companies in the Czech Republic.

Key words: Wide Area Monitoring, PMU, Synchrophasor.

PHASORS

The definition of phasors, mathematic formalization of the vector error, recommendations for phasor measurement and definition of communication protocol suitable for transfer of phasor data are defined in the IEEE standard C37.118 and in older standard IEEE 1344.

The electric quantities (1. harmonics of voltage and current) are defined by the equation

$x(t) = X * \cos(\omega*t + \varphi)$,

where φ is angle – rotation of vector in the time t=0.

The phasor is vector characterized by amplitude X and angle φ.

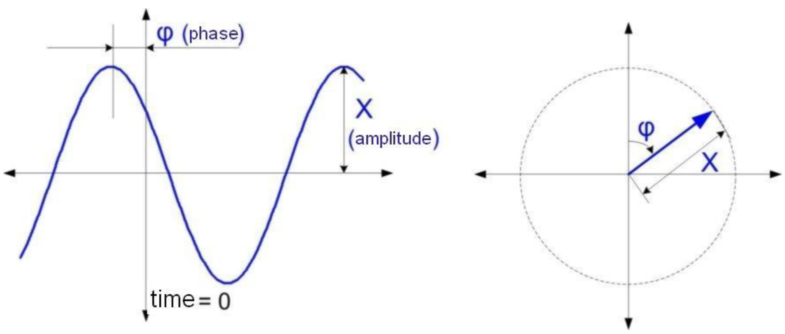


Fig. 1. Phasor representation

Phasors in various network nodes can be measured exactly in the same time using precise time synchronization of measurement. The set of phasors data measured synchronously in various places and completed by time information represents set of absolute synchrophasors.

Using the set of synchrophasor data, we can analyze angle between synchrophasors measured in the same time and change of synchrophasor angle in a time. It is also possible to select one of the available synchrophasors as reference measurement with $\varphi_r=0$ and to relate other measurements to the reference value. In such case we'll get set of relative synchrophasors with the reference value of a selected measurement.

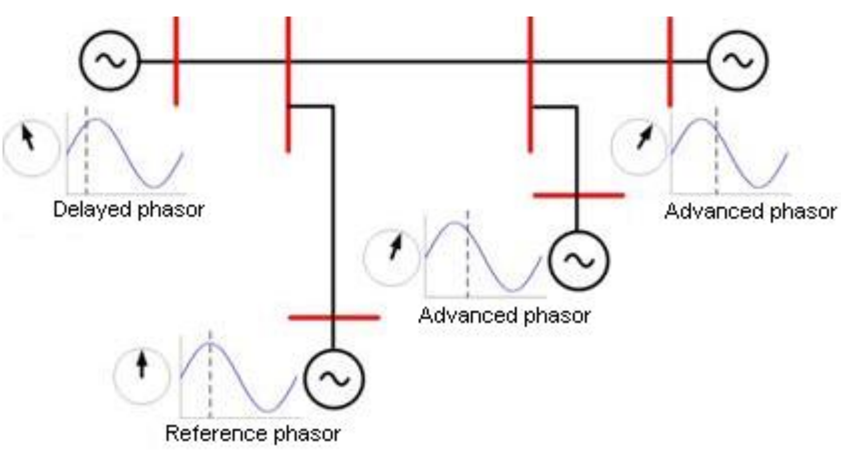


Fig. 2. Snap of relative phasors with reference measurement

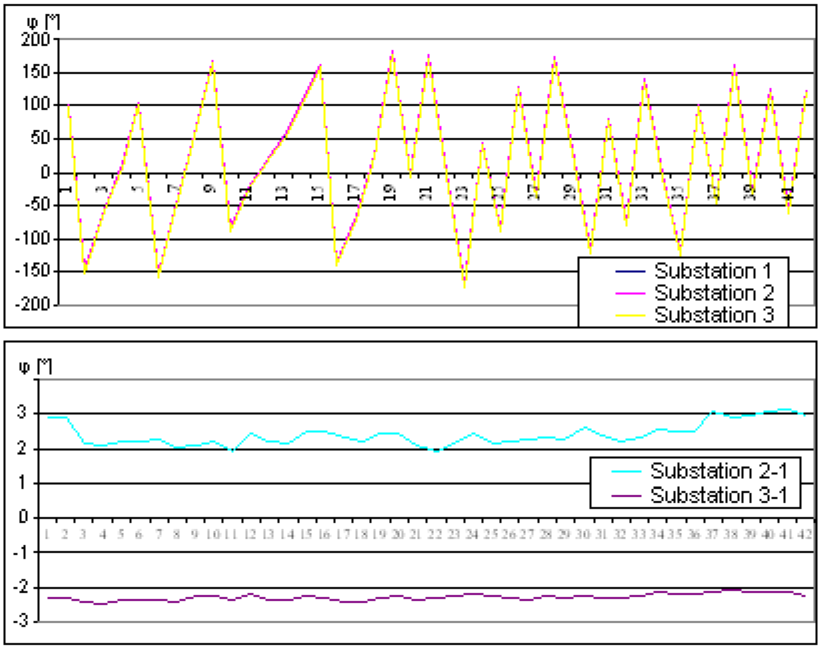


Fig. 3. Sample of synchronous and relative phasors (Substation 1 is selected as reference measurement)

MEASUREMENT SYSTEM

Voltage synchrophasors are mostly measured in bus bars or in selected outlets in electric substation. Current synchrophasors are measured in outlets.

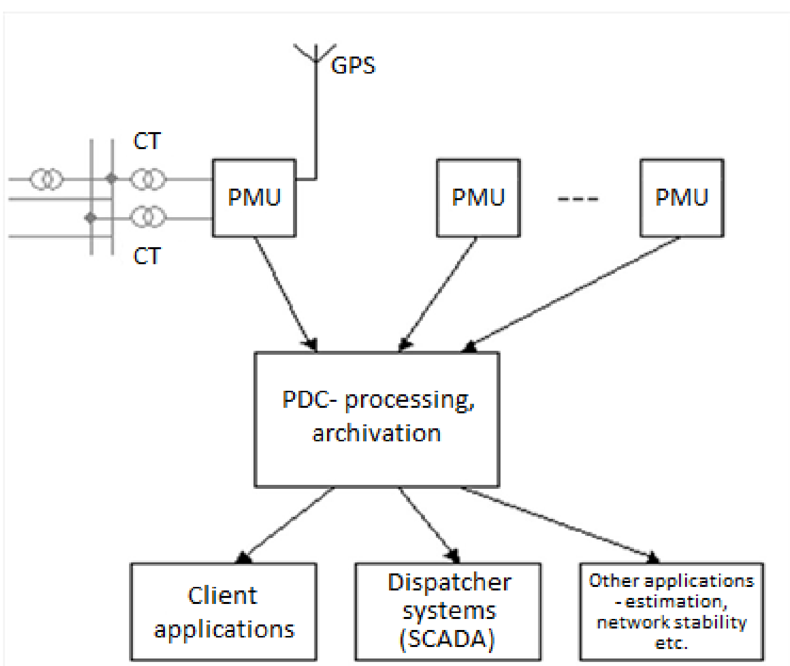


Fig. 4. Structural scheme of synchrophasor system

The synchrophasor systems consist of:

Measurement devices

Phasor measurement devices are called Phasor Measurement Units (PMU) in the English literature. The functionality of PMU is defined by the IEEE standard. Measurement of voltage is used in most cases because measurement of current shows bigger angle error caused by error of current instrument transformers. Parameters of measurement are defined by IEEE standard in a wide range which leads to difficulties in comparing results between devices from different manufacturers. The reporting rate ranges from 50 (60) samples per second to 1 sample per second.

Communication infrastructure

Communication between PMU and PDC significantly affects possibilities and usability of the system. There are very different requirements for various applications namely in the following parameters:

- Delay during data transfer, i.e. time required to get available data for applications (latency)
- Reporting rate
- Amount of data transferred from PMU to PDC

E.g. delay of data transfer for application related to protection of wide networks in real time is required in the range up to tens of milliseconds. Delay of data transfer for the purpose of estimation applications can be in the range of ones of seconds.

Phasor servers

PDC (Phasor Data Concentrator, phasor server) is represented by a server organizing collection of data from PMU, data pre-processing and data storage in the database available for related applications.

Suitable structure of PDC servers (layered and multiplied organization) can assure:

- Integration character of implemented system, i.e. possibility to integrate various PMU types from different manufacturers
- Distribution of computing power according to the requirements of various applications (e.g. applications requiring data transfer with low delay and at the same time no data from other sources can be hosted in local PDC)
- Possibility to provide data with different quality to various users (e.g. various departments of one company)
- Cooperation with other information systems e.g. SCADA (data sharing) or other application programs or systems.

Various requirements for data processing and amount can be also solved by usage of local PDC placed directly in the electric substation. Local PDC servers can pre-process and aggregate data and also to run selected applications.

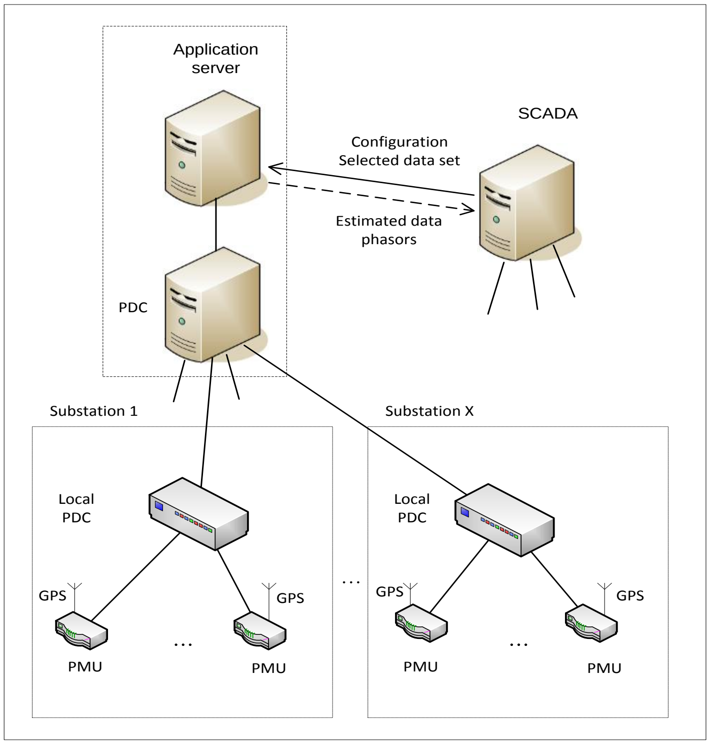


Fig. 5. System with local PDC

PRECISION OF ANGLE MEASUREMENT

Precision of phasor (precision of time synchronization, precision of angle and amplitude) affects possibilities of phasor usage. The following table shows requirements for optimal precision of timestamp for some applications (source: Bonneville Power Administration):

Function	Parameter	Precision of synchronization	Time source
Fault locator	300 meters	1 µs	GPS
Phasor measurement	+/-0,1 degree	5,5 µs (50Hz)	GPS
Network stability	+/-0,1 degree	5,5 µs (50Hz)	GPS
Fault recorder	Comparison of records	1 ms	GPS, DCF77

TABLE 1 – REQUIREMENTS FOR PRECISION OF TIMESTAMP

Precision of measurement is affected by all parts of the measurement chain. The following influences have to be taken into consideration when user requirements are analyzed:

- Instrument transformers of voltage and current. Measurement error depends on the accuracy class and transformer load (25 – 100% of load results in error 2˚ - 0.08˚). Error of current instrument transformers is significant because measurement is done within the entire transformer range.
- Input circuits with isolation and anti-aliasing filter causes measurement shift. The shift can be the same for all devices from the same producer in the ideal case and can be compensated in the data processing. Stability of input circuits has to be ensured.

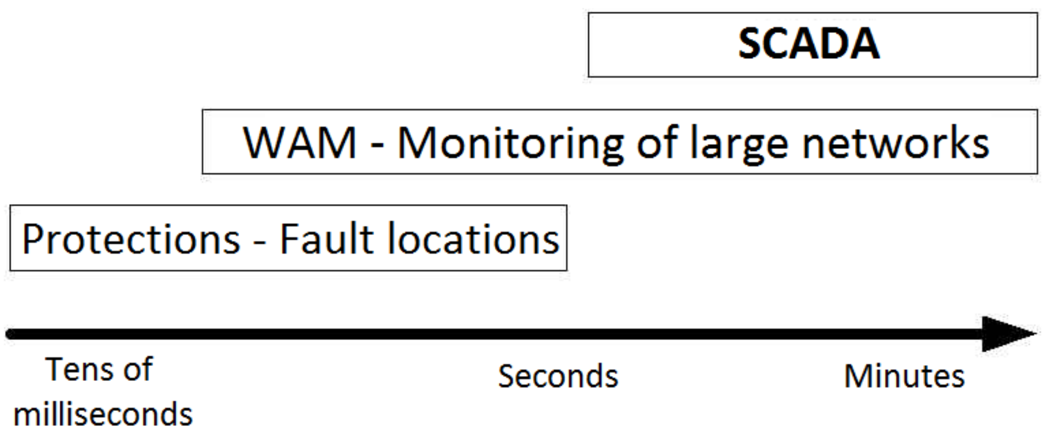
- The precision of GPS time synchronization is 20ns to 500ns according to the manufacturer's data. Another error can be caused by the transfer and processing of synchronization pulse. Error of 5.5μs in time synchronization represents error of 0.1˚ in the phasor measurement.
- Method of analysis affects the quality of measurement mostly for the purposes of comparison with systems from various PMU producers. It represents sampling frequency, length of measurement window and frequency of processing and data transfer. Algorithms used for calculation of synchrophasors affect the quality of results from the point of view of dynamics (speed and accuracy of response time).
- Further parts of the measurement chain (communication subsystem, data processing in PDC, transfer of data to the user) do not affect the quality of data but the delay of data usability. Parameters of these parts of measurement chain affect usability of data in various applications.

The following table shows estimated contribution of individual components to the overall error:

Source of error	Angle error	Time error
Time synchronization	±0,02˚	±1μs
Primary instrument transformers (accuracy class 0.3)	±0,3˚	±16,5μs
Error of measurement devices and error of calculation method	±0,1˚	±5,5μs

TABLE 2 – CONTRIBUTION TO OVERALL ERROR

Requirements to measurement/communication speed for various systems:



WAMS IN THE WORLD

Operators of transmission and distribution systems are interested in recent years in usage of synchronous phasors (SF) and generally SF based systems:

- **WAMS** (Wide Area Monitoring System –SF are used for monitoring of operation and events in the system)

- **WACS** (Wide Area (Stability) Control System – system generates action measures based on continuous evaluation of operational situation)
- **WAPS** (Wide Area Protection System – adaptive systems of protection utilizing SF)
- **WAMPAC** (Wide Area Monitoring, Protection and Control).

These systems contribute to increased security and reliability of network operation, prevention of dangerous situations and blackouts, which are actual and urgent requirement of system operators increased by ongoing changes of the operational state, e.g. increased load, power transits from the places of concentrated production over large distances. These changes sometime force operation without the „N-1“ criterion, i.e. operation on the limit of safety. Positive factor for expansion of WAMS is also availability of devices for measurement and processing of SF and communication systems with suitable bandwidth and low latency. WAMS technology has undergone last 10 years of explosive development from „academic curiosity“ to the current state, which is already providing solutions that cannot be achieved by traditional approaches of SCADA/EMS systems or only with great complications. WAMS technology allows a new view of the processes taking place in the system.

Dispatcher needs information derived from the system state, not a gigabytes of synchronous data to support his decisions. Special applications developed for this purpose are supplied as part of WAMS server PDC. These applications are described in separate paper.

Information about expansion of WAMS in various parts of world is available from public sources, namely internet. WAMS are built as a basic source of information in the wide and quickly developing networks with massive use of PMUs.

The following figure shows situation several years old. Available information can be mostly obtained from operators of transmission networks. Operators of distribution networks also use WAMS, however this information is usually not publicly available. Exception is represented by CIRED conference where SF was mentioned already in 2005 (CIRED Torino).

The most of European operators are associated and connected within the ENTSO-E (formerly UCTE). The issues of stability, security and reliability of operation are increasingly important in the large network and WAMS represent significant contribution to that purpose. The survey map of Europe from 2009 shows equipment of transmission networks. WAMS was also installed in the transmission network of Czech Republic in 2013. Some installations of WAMS are experimental, some are fully functional and used.

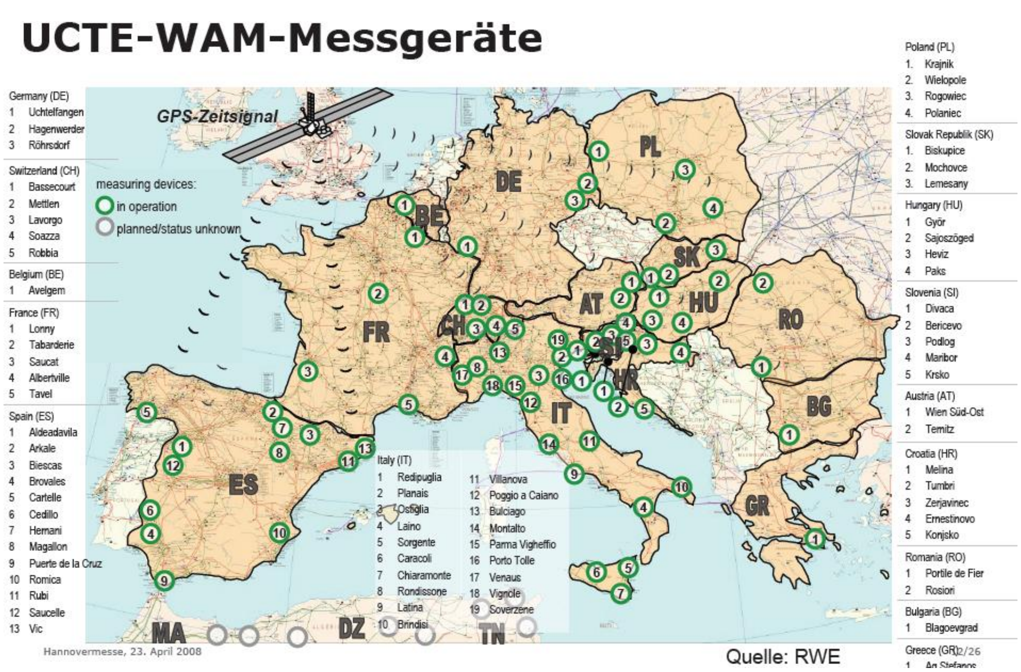


Fig. 6 Installation of PMU in UCTE (ENTSO-E) Source: RWE

Russian intention to monitor electric network especially in the areas of energetic potential is very interesting. Emphasis is also put on the monitoring of cross-border lines for control and management of energy transfer to neighboring countries.

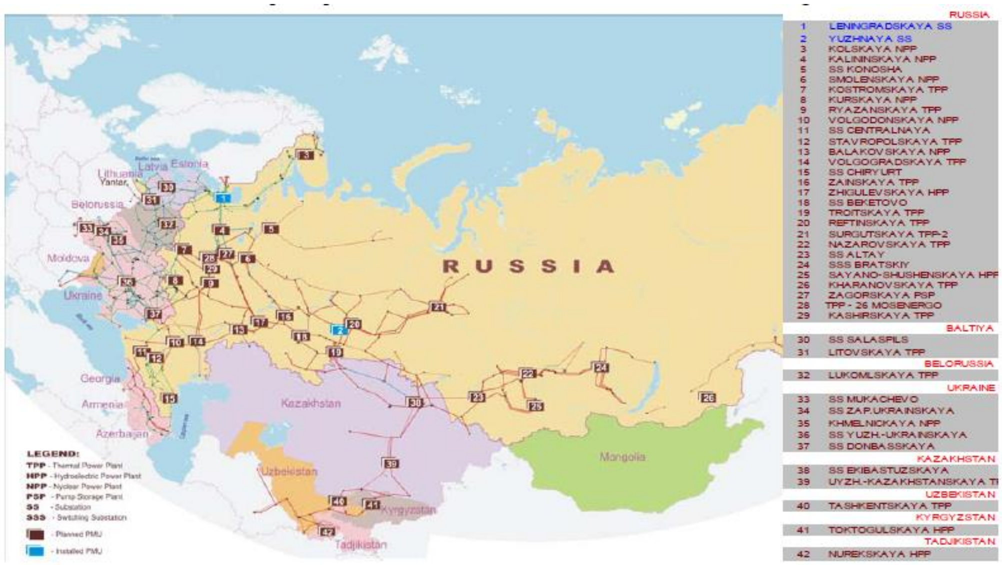


Fig. 7 Planned placement of PMU in Russia and neighboring countries
Source: / B.I.Ajujev et al.: IPS/UPS Wide Area Measuring System. Paper C2-211, CIGRÉ 2006, Paris /

CONCLUSION

Experience with applications of WAMS raised some important conclusions:

- WAMS systems in distribution networks will be used for monitoring and control of distributed sources (intermittent sources).
- The WAMS benefits are significantly better if the system covers bigger scope of interconnected systems, i.e. if the SF measurement is interchanged between individual TSO.
- WAMS outputs expand the functionality of existing systems of early warning. The WAMS allows detection of potentially critical states and also unstable dynamic states.
- Applications allowing effective usage of WAMS outputs for operative dispatch control, i.e. on-line operation represent significant contribution to the present way of control.
- The trend probably leads to systems WAMPAC (Wide Area Monitoring, Protection and Control) that represent one of assumptions of Smart Grids in the transmission systems. Such systems need more PMU or PMCU units.

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